

# **Example Root Cause Analysis Report**





**ABS Group INC.**

**1000 Technology Drive  
Knoxville, Tennessee 37932-3353  
(423) 966-5232 Fax (423) 966-5287**

## **TRANSMITTAL OF INCIDENT INVESTIGATION REPORT**

Larry, enclosed is one copy of the *Investigation of the Acrylic Kettle (X-10) Incident on December 7, 1999*. This is our deliverable as proposed in JBFA-97-999.

The enclosed report describes the composition of the incident investigation team, the methodology employed by the team, a brief description of the incident, a summary of the sequence of events, a brief discussion of the causal factors, and recommendations for preventing recurrence. The attachments provide details, drawings, and figures related to this incident.

We have made appropriate report revisions to address reviewer comments on the draft copy. If we do not receive additional comments within 3 months of sending this letter report, or if the report is acceptable as is, the enclosed copy will serve as the final report. For our records, we ask that your company send us a brief letter of acceptance of our final report within the next few weeks.

*The incident investigation report and recommendations were prepared by a team of ABS Group Inc., Risk and Reliability division (ABS Group) and your personnel solely for the use of your company. Neither ABS Group, your company, nor any person acting in their behalf makes any warranty, expressed or implied, or assumes any liability to any third party with respect to the use of any information or methods disclosed in this letter report. Any third-party recipient of this letter report, by acceptance or use of this letter report, releases ABS Group from liability from any direct, indirect, consequential, or special loss or damage, whether arising in contract, tort (including negligence), or otherwise.*

*ABS Group and its employees, subcontractors, consultants, and other assigns cannot, individually or collectively, predict what will happen in the future. ABS Group has made a reasonable effort, based on information supplied to us by your company, to identify the causes of the X-10 incident so that your company can reduce the likelihood of accidents and to meet the requirements of the OSHA process safety management (PSM) regulation (29 CFR 1910.119[m]). However, even if all the suggestions from this effort are followed, accidents may still occur. Moreover, the actions associated with implementing the suggested improvements may subject plant employees or their assigns to unforeseen hazards. Therefore, your company should independently evaluate all recommendations before implementing them to ensure they do not create new hazards. Also, federal and state regulations are subject to interpretation; we cannot guarantee how they will be interpreted in the future. Thus, ABS Group accepts no liability for any regulatory impact or for any incident that may occur in any of your facilities.*

Thank you for choosing ABS Group to help you meet your process safety objectives. We look forward to working with you on other tasks.

Sincerely,

Donald K. Lorenzo  
DKL:sbr

Enclosures

# Investigation of the Acrylic Kettle (X-10) Incident on December 7, 1999

## Summary of the Incident

On December 7, 1999, at approximately 11:00 p.m., the acrylic kettle (X-10) at PSI's Denver plant ruptured during production of a batch of resin (G24X104). The kettle contents were ejected, and the surrounding structures were severely damaged. The kettle operator was taken to the hospital where he recovered from second-degree burns. Small fires that were started by the materials sprayed from the kettle burned out or were quickly extinguished by plant personnel. The entire plant was shut down pending investigation of the incident and repair of the damage caused by the fire, explosion, and falling debris.

## Incident Investigation Team

The incident investigation began on December 8, 1999, at 11:00 a.m. Larry Saunders was initially in charge of the investigation; Steve Whittle assumed responsibility for the investigation on October 6. The incident investigation team included:

Name	Title	Organization
Lee Stevens	Production Consultant	PSI Pardeville, Wisconsin
Steve Whittle	Incident Investigation Leader Senior Process Analyst	PSI Corporate
Mike Roberts	PSM Project Leader	PSI Corporate
Mike Eislie	Assistant Plant Manager	PSI Denver, Colorado
Ken Rutgers	Acrylic Unit Operator	PSI Houston, Texas
Dave Wage	PSM Project Leader	PSI Corporate
Kyle Hoops	Acrylic Unit Operator	PSI Denver, Colorado
Bill Bridges	Consultant	ABS Group Inc.
Don Lorenzo	Consultant	ABS Group Inc.
Lee Vanden Heuvel	Consultant	ABS Group Inc.

## Investigation Methodology

The investigation team collected data concerning the incident. Data collection began on December 8, 1999, and continued until December 18, 1999.

The data collected were then summarized in an Event and Causal Factors Chart (Attachment 1). This chart was used to help the investigators decide in what areas more data were necessary, and it also helps to clearly depict the relationship of key events related to the incident.

Finally, the team developed recommendations for plant management to consider. The recommendations relate to reducing or eliminating the key causal factors; therefore, addressing these recommendations should help prevent recurrence in the remaining acrylic kettle (K-25).

## **Personnel Involved in the Incident**

Nick Faldo was the senior acrylics area operator working at the time of the incident. Lee Heuvel was an experienced kettle operator being trained for a new assignment in the acrylics area. He had been working in acrylics for about 7 weeks.

## **Process Description**

There are two production units in adjacent buildings in the acrylics area — an older kettle (X-10) and a newer kettle (K-25), each with its own feed and product tanks. A variety of acrylic resins are produced by reacting acrylate monomers with catalysts in these kettles.

To make a batch, the desired amount of monomer is transferred from a storage tank to the monomer feed tank. Xylene solvent is pumped from storage into the kettle and the catalyst mix tank. Liquid or powdered catalyst is added to the xylene in the catalyst mix tank and blended with a small agitator. (To improve safety, production procedures were recently revised to require dilution of all catalysts with xylene; previously some catalysts had not been diluted.)

Initially, the xylene in the kettle is heated to its boiling point and refluxed through a decanter to remove any water. When the xylene is clear (water-free), the reflux is routed directly back to the kettle, bypassing the decanter. The catalyst/xylene mixture in the mix tank and the monomer in the feed tank are then pumped into the kettle at the desired rates. Steam heating through the kettle's jacket and internal half-pipe coils is maintained until the exothermic polymerization is initiated, then steam flow is stopped and cooling water is circulated.

When the batch is completed, the resin is transferred to a product tank or discharged directly to drums. The kettle is cleaned, if necessary, and the next batch is started.

## **Description of the Incident**

On December 7, 1999, at approximately 5:30 p.m., the day shift began a batch of acrylic resin (G24X104) in kettle X-10. About 13,200 pounds of n-butyl acrylate monomer were pumped into the feed tank, 3,700 pounds of xylene were pumped into the kettle, and 246 pounds of xylene were pumped into the catalyst mix tank. The kettle agitator was started, and the steam valve to the kettle jacket and coil was opened to begin heating the xylene. One partial drum (204 pounds) of di-tert-butyl peroxide catalyst (DTBP) was pumped into the catalyst mix tank before shift change at 7:00 p.m.

The night shift operators, Lee Heuvel, and Nick Faldo continued work in the acrylic area. Lee, under Nick's supervision, took the lead in completing the batch in X-10 while Nick attended to drumming product from K-25 so a new batch could be started in that kettle. Lee got another DTBP catalyst drum and pumped the additional 42 pounds of catalyst needed from the drum into the catalyst mix tank. The catalyst and xylene in the catalyst mix tank should have then been agitated for 30 minutes, but this was apparently not done, either because the operator failed to start the mixer or because the mixer tripped off shortly after startup. (Lee does not specifically remember starting the agitator, but it is a routine, almost reflexive, task for an experienced operator.) Post-incident testing showed that without mechanical mixing, most of the catalyst could have remained floating as a separate liquid layer on top of the xylene in the catalyst tank. (Tests also showed that catalyst and xylene are miscible and, once mixed, they do not separate.)

Meanwhile, Lee continued to prepare the kettle. The xylene in X-10 was heated to 280 °F and refluxed through the decanter to remove any water contamination that could degrade product quality (requiring filtration to remove the haze). Once the xylene was dry (about 10:00 p.m.), Nick verified the system status before Lee proceeded. Nick recalled that the catalyst mix tank agitator was off at this time, but it would have normally been shut down before feed to the kettle was started because the agitator vibration caused erratic weigh cell readings. There was no other visible indication whether the catalyst had been mixed, and Nick did not specifically question Lee about it. The valve alignment was correct, so Nick told Lee to proceed with feeding the kettle.

At about 10:05 p.m., Lee started feeding both monomer and catalyst at the desired rates. The monomer feed is relatively cool (50 °F to 60 °F), so the kettle temperature normally drops 10-15 degrees during the first 10-20 minutes of a batch. Lee correctly applied steam to the kettle jacket and internal half-pipe coils during this phase to heat the batch and initiate the exothermic reaction. (Note: It is possible that the steam flow was low despite a normal valve position [4-5 threads open], but this seems unlikely because the steam was operating normally during the earlier reflux step.) Nick checked with Lee about 10 minutes later and verified that the reaction was proceeding normally (the temperature had dipped, steam was on, and Lee believed he saw some reflux), so Nick returned to work at K-25. The reaction, however, did not start normally because the “catalyst” being fed was probably unmixed xylene from the bottom of the catalyst tank. Without the normal heat of reaction (or perhaps, but less likely, because of inadequate steam heat), the batch temperature continued to fall and unreacted monomer accumulated in the kettle.

The temperature dropped to 240 °F by about 10:20 p.m. before beginning to rise. At 10:55 p.m., the temperature had risen to 245 °F and Lee believed the reaction had initiated. He closed the steam valve, but the temperature promptly dropped back to 240 °F, so Lee applied more steam to the kettle to heat it back up to the normal range. When Nick checked with Lee about 11:00 p.m., he saw that the kettle temperature was abnormally low and that the steam was still on. Nick told Lee to cut back the steam flow and be ready to apply cooling water as soon as he saw any temperature rise. Nick returned to K-25.

By then, about 7,000 pounds of monomer had been fed to the kettle with the dilute xylene/DTBP mixture from the bottom of the catalyst mix tank. The concentration of DTBP in the remaining catalyst mixture was probably much higher, and it finally initiated the polymerization reaction as it was fed to the kettle. Lee shut off the steam and vented the kettle jacket about 3 minutes later when he saw the temperature had risen to 266 °F. Lee began to open the cooling water valves, but it was too late to control the runaway reaction of the unreacted monomer that had accumulated in the kettle. Xylene was vaporized in the kettle so fast that it overwhelmed the reflux condenser, overwhelmed the vent system, overwhelmed the pressure relief system, and overpressurized the kettle.

Shortly after 11:00 p.m., the welded joint between the kettle head and side wall failed around the entire circumference, and the head was launched upward, demolishing all the structure above it. The flashing kettle contents were also ejected upward and ignited in a small fireball/explosion. The resulting pressure wave damaged surrounding structures, and debris fell in a radius of about 300 yards. Burning ejecta started several small fires around the plant, but these were quickly extinguished. Lee was hospitalized with second-degree burns; no other injuries were recorded as a result of the incident.

## Contributing Factors

- Lee was a relatively new operator in the acrylics area, but he had an excellent performance record as a kettle operator in another area of the plant. He did not have enough experience with this formulation to recognize when to stop the feed streams if the batch was not progressing normally.
- Overtime had been authorized for an extra operator to stay over and train Lee. When unexpected schedule conflicts arose, no one was available to work the extra overtime as a trainer. Thus, the other operator on Lee's shift (Nick) had to divide his attention between normal work duties and training.
- The operators did not know that catalyst and xylene would not mix well unless mechanically agitated. Their perception was that mixing ensured a uniform solution and enhanced quality, but that simply pumping the two materials into the same tank would largely mix them.
- The operators had to turn off the catalyst mix tank agitator to get accurate readings from catalyst mix tank weigh cells so they could set the correct catalyst feed rate. This increased the likelihood of failing to agitate the catalyst/xylene mixture.
- The operating procedures specified only the desired temperature for the reaction. There were no safety limits stated, and no warning that feeding reactants below a certain temperature could result in accumulation of unreacted material and a subsequent runaway reaction when the unreacted material was heated to the catalyst activation temperature.
- The pressure relief system for the kettle was designed for a different manufacturing process. When the process was changed to produce acrylics, the relief system was not resized.

## Recommendations

1. Review the design basis for the pressure relief system on the remaining acrylic kettle (K-25) to ensure that it is capable of handling a runaway reaction.
2. In the instructions for each acrylic product, specify the safe range of kettle temperatures at which monomer and catalyst may be fed.
3. Consider providing an interlock(s) to halt feed to an acrylic kettle if its temperature is outside safe limits.
4. Revise the acrylic manufacturing procedures to specify that the catalyst mixer be turned on, and have operators verify the mixer status before starting to feed monomer to the kettle.
5. Consider providing an interlock to prevent/halt monomer and catalyst feed to an acrylic kettle if the catalyst mixer is not on. (Vibration does not cause erratic readings from the weigh cells under the catalyst feed tank for K-25.)
6. Consider providing a means for operators to see the history and trend of temperature in an acrylic kettle during a batch.
7. Specify the criteria for a qualified acrylic unit operator. What information must be known and what skills must be demonstrated before a worker is considered qualified to operate without a trainer's supervision?
8. Specify the requirements for an on-the-job trainer. What other duties is a trainer allowed to undertake while coaching a trainee?

## Root Cause Analysis Results

Causal Factor	Paths Through the Root Cause Map™	Recommendation
<p>#1 - The agitator for the catalyst mix tank was not turned on during the dilution of the catalyst with xylene, or it tripped off shortly after starting.</p> <p>Xylene is used to dilute the catalyst. This practice was recently started (as a result of an unrelated incident) to reduce the probability of catalyst decomposition in the feed nozzle. Xylene is pumped into the catalyst mix tank first, and catalyst is then pumped in on top of it. If the agitator for the tank is not turned on, the catalyst/xylene can stratify with the lighter di-tert-butyl peroxide (DTBP) on the top and the heavier xylene on the bottom. When the catalyst is then added to the kettle, the xylene-rich phase is added first. When the more concentrated catalyst phase is added later, the relatively large quantity of unreacted monomer that had accumulated could react more vigorously.</p>	<p>Procedures</p> <ul style="list-style-type: none"> <li>– Wrong/incomplete</li> <li>– Incomplete/situation not covered</li> </ul> <p>There was no step in the procedure specifying that the catalyst mix tank agitator be turned on.</p> <p>Immediate Supervision</p> <ul style="list-style-type: none"> <li>– Supervision during work</li> <li>– Supervision less than adequate (LTA)</li> </ul> <p>The trainee operator was required to work independently with only intermittent supervision by the qualified operator who was working overtime as a trainer. The qualified operator divided his attention between training the new operator and draining product from the adjacent kettle.</p> <p>Training</p> <ul style="list-style-type: none"> <li>– No training</li> <li>– Training requirements not identified</li> </ul> <p>The trainee operator was an experienced kettle operator from a different area of the plant. There were no clear performance standards to indicate when the operator had been adequately trained on the acrylic unit.</p>	<p>1. Implement a pre-startup safety review program to ensure that procedures are properly revised when changes are made and that workers are trained in the revised procedures.</p> <p>2. Define the required minimum staffing of qualified operators for each shift. Prohibit the use of trainees to fill the role of a qualified operator.</p> <p>3. Develop a written program for initial and refresher operator training, including specific requirements for demonstrating understanding of the training.</p>
	<p>Training</p> <ul style="list-style-type: none"> <li>– Training LTA</li> <li>– On-the-job training LTA</li> </ul> <p>Human Factors Engineering</p> <ul style="list-style-type: none"> <li>– Intolerant system</li> <li>– Errors not detectable</li> </ul> <p>The only indication that the mixer was on was the mixer shaft rotation. (The small motor could not be heard above other background noise.) The mixer had to be turned off so it would not interfere with the weigh cell readings during catalyst feed. There was no visual cue that the mixer had not been operated.</p>	<p>4. Define the expectations for qualified operators serving as on-the-job trainers. Train those operators on how to be effective trainers.</p> <p>5. As part of the process hazard analysis (PHA), analyze the human-machine interface to ensure that there are adequate alarms and indications of safety-related parameters.</p>

## Root Cause Analysis Results (continued)

Causal Factor	Paths Through the Root Cause Map™	Recommendation
<p>#2 – Hazards of inadequate catalyst mixing were not recognized.</p> <p>Operators were unaware that the DTBP solution was less dense than xylene and were unaware that a low catalyst concentration could exist in the bottom of the mix tank. They believed that pumping the DTBP into the xylene would largely mix the two. They were also unaware that feeding catalyst into a kettle with an accumulation of unreacted monomer could release enough energy to rupture the kettle.</p>	<p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>Standards, policies, or administrative controls (SPAC) LTA</li> <li>Not strict enough</li> </ul> <p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>Safety/hazard review</li> <li>Review not performed</li> </ul> <p>The catalyst vendor recommended diluting the catalyst to make it less reactive, and therefore safer, to add to the acrylic kettle.</p>	<p>6. Revise the policy specifying the process safety information that must be transmitted to the plant, along with any formulation revisions, so management-of-change reviews can be properly performed and appropriate cautions and warnings can be incorporated into the procedures and training programs.</p> <p>7. Implement a management-of-change program to ensure that all process changes are reviewed, including those that result from incident investigations or hazard studies.</p>
<p>#3 – Operators failed to recognize unstable process conditions and stop kettle feeds.</p> <p>Temperature in the kettle decreased to 240 °F during the addition of monomer. The kettle temperature is supposed to be maintained at 270-285 °F during the addition of monomer. Monomer addition causes the kettle temperature to decrease because it is relatively cold (typically 55-65 °F). Kettle temperature is maintained by controlling steam flow to the kettle. Kettle steam flow was only partially on.</p> <p>The qualified operator failed to recognize that continuing to feed monomer while the kettle temperature was too low could lead to an uncontrollable runaway reaction. The digital temperature indication gave no indication of the reaction history.</p>	<p>Procedures</p> <ul style="list-style-type: none"> <li>Wrong/incomplete</li> <li>Situation not covered</li> </ul> <p>Operators indicated that they had general guidelines for maintaining the kettle temperature while adding monomer. However, there were no safe limits specified for this system and no clear guidance for actions to be taken when the temperature fell outside these bounds.</p> <p>Training</p> <ul style="list-style-type: none"> <li>Training LTA</li> <li>Abnormal events/emergency training LTA</li> </ul> <p>Operators did not realize the severe consequences associated with accumulating unreacted monomer in the kettle. The operator was more concerned about overheating the kettle and did not add more steam quickly to initiate the reaction.</p>	<p>8. Develop safe operating limits for process parameters and state them in the procedures. Include procedural instructions on how to respond if operating limits are exceeded.</p> <p>9. Train operators in recognizing potential upsets and in the proper corrective action. Emphasize that stopping feed to exothermic reactions is a preferred option, not a last resort.</p>
	<p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>Safety/hazard review</li> <li>Review not performed</li> </ul> <p>The PHA was not performed because the unit was scheduled for shutdown 2 years ago. A PHA team may have identified this accident scenario and recommended additional or revised safeguards.</p>	<p>10. Develop complete process safety information, including reaction kinetics, for each formulation manufactured and update all PHAs based on this information.</p>

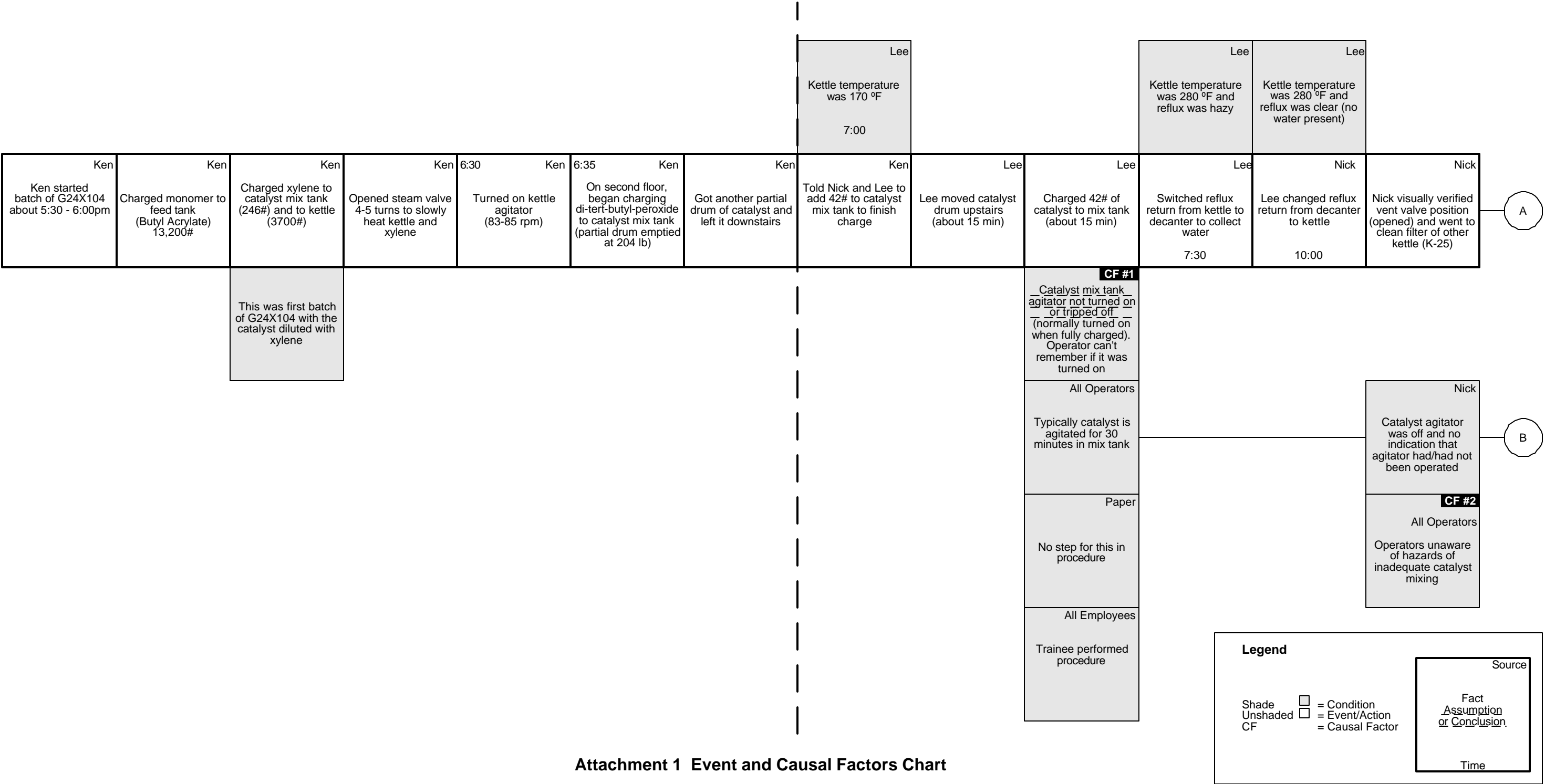
## Root Cause Analysis Results (continued)

Causal Factor	Paths Through the Root Cause Map™	Recommendation
<p>#3 – (continued)</p>	<p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>– SPAC LTA</li> <li>– No SPAC</li> </ul> <p>Previous events occurred where the kettle temperature and pressure had fallen outside the acceptable range. In at least one previous event, the temperature had reached 350 °F (the acceptable range was 270-285 °F), and pressure had reached 20-25 psig (the acceptable range is -3 to +3 psig). Had that incident been reported/ investigated, the procedures and training might have been revised and this incident avoided.</p>	<p>11. Develop a program for investigating near misses as well as incidents.</p>
<p>#4 – The kettle pressure relief system appears to be undersized.</p> <p>As pressure in the kettle increased, the relief system was unable to adequately relieve the pressure. The pressure relief system consists of a rupture disk upstream of a relief valve.</p> <p>The pressure relief line appears to be undersized. The relief valve was a 1.5 x 2-inch valve. The new acrylic kettle (K-25) has an 8-inch rupture disk relieving to atmosphere in addition to a 1.5 x 2-inch valve.</p>	<p>Human Factors Engineering</p> <ul style="list-style-type: none"> <li>– Workplace layout</li> <li>– Displays LTA</li> </ul> <p>The system did not provide the information needed by the operator. The digital temperature indication does not provide any trend information that the operator can use to see whether the batch temperature is behaving normally.</p>	<p>12. As part of the PHA, analyze the human-machine interface to ensure that there are adequate alarms and indications of safety-related parameters.</p>
	<p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>– Document and configuration control</li> <li>– Control of official documents LTA</li> </ul> <p>There was no documentation of the design basis for the pressure relief system.</p>	<p>13. Develop a data management system for process safety information, including the design bases for pressure relief devices and ventilation systems, for all process equipment.</p>
	<p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>– Safety/hazard review</li> <li>– Review not performed</li> </ul> <p>The kettle was used to make epoxies about 5 years ago before it was changed to make acrylics. There is no record that the hazards associated with the change were reviewed or that the relief system sizing was reevaluated.</p>	<p>14. Implement a management-of-change program to ensure that all process changes are reviewed and that the process safety information is updated to reflect those changes</p> <p>15. Develop a policy specifying the information that must be transmitted to the plant, along with any new formulations, so management-of-change reviews can be properly performed.</p>
	<p>Design Input/Output</p> <ul style="list-style-type: none"> <li>– Design input LTA</li> <li>– Design input not correct</li> </ul> <p>A previous manager decided that external fire was the maximum credible design basis for kettle pressure relief systems. There was no evaluation of other, potentially more demanding, design bases for the pressure relief system.</p>	<p>16. In the process safety information, document that all equipment conforms to good engineering practice (i.e., conforms to current codes and standards) or document the analysis concluding that the equipment is safe for continued use in its current application (even if it does not conform to current codes and practice).</p>

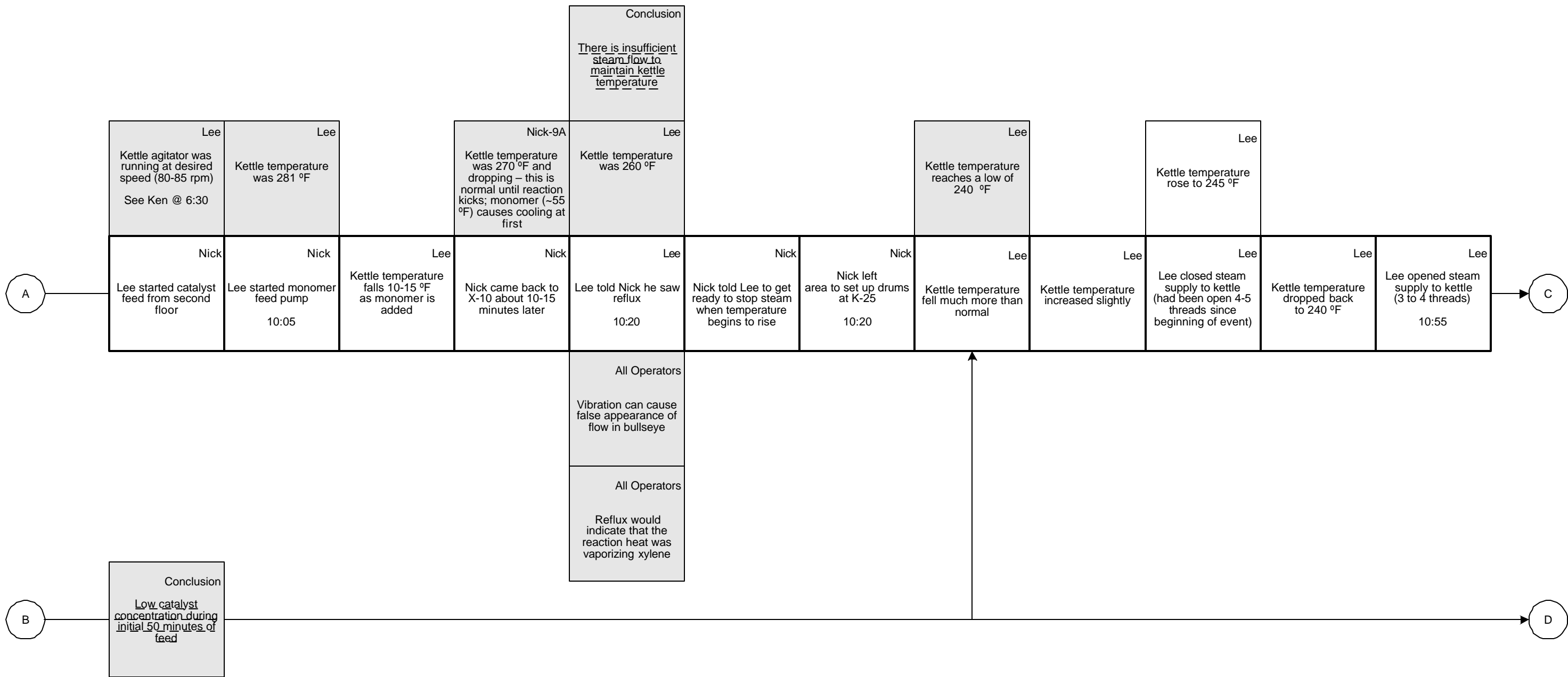
### Root Cause Analysis Results (continued)

Causal Factor	Paths Through the Root Cause Map™	Recommendation
<p>#5 – The kettle appears to have failed below its design burst pressure.</p> <p>Visual inspection of the kettle top (which was blown off the kettle and landed approximately 50 feet from the kettle) indicates that much of the fracture occurred previously. Some areas of the break are shiny, indicating that the break occurred recently; other areas of the break show significant oxidation, indicating that there was an existing crack in that area.</p>	<p>Inspection/Testing Program</p> <ul style="list-style-type: none"> <li>– Inspection/testing program LTA</li> <li>– Routine testing program LTA</li> </ul> <p>The kettle was normally operated near atmospheric pressure and was slated for decommissioning, so vessel inspections were given low priority. Records of the last inspection could not be located.</p> <p>Administrative/Management Systems</p> <ul style="list-style-type: none"> <li>– Corrective action</li> <li>– Corrective action LTA</li> </ul> <p>Operator observation of "weeping" from the weld joint indicated that the weld integrity was suspect, but no corrective action was taken.</p>	<p>17. Develop a mechanical integrity program to ensure that equipment is fit for its intended use over the life of the facility. Ensure that equipment records are kept current.</p> <p>18. Ensure that deficient equipment is repaired, derated, or removed from service when tests or inspections indicate a deficiency.</p>
<p>#6 – Emergency response was delayed. (Not shown on causal factor chart)</p> <p>After the incident, the emergency response was delayed because the operators could not get through to 911 and because no one on site had a key to the main gate.</p>	<p>Communications</p> <ul style="list-style-type: none"> <li>– No communication or not timely</li> <li>– No method available</li> </ul> <p>Training</p> <ul style="list-style-type: none"> <li>– Training LTA</li> <li>– Abnormal events/emergency training LTA</li> </ul>	<p>19. Provide a more reliable means to summon outside responders in an emergency.</p> <p>20. Exercise the emergency response plan periodically to ensure that it will be effective on all shifts. Revise the plan as necessary and train personnel in their proper roles.</p>

Shift  
Change  
7:00 PM



Attachment 1 Event and Causal Factors Chart

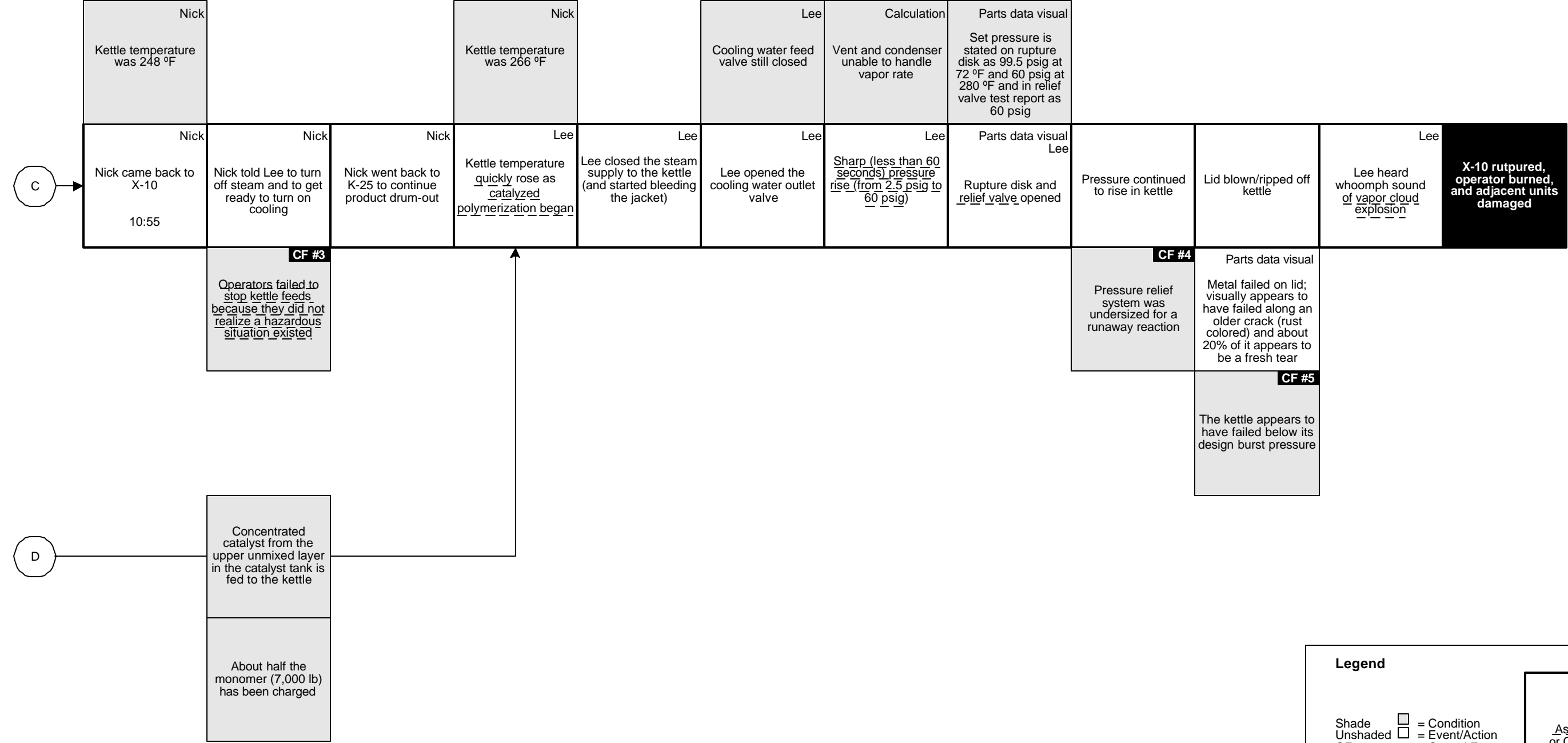


Attachment 1 Event and Causal Factors Chart (cont'd)

**Legend**

Shade ☐ = Condition  
Unshaded ☐ = Event/Action  
CF ☐ = Causal Factor

Source
Fact Assumption or Conclusion
Time



Attachment 1 Event and Causal Factors Chart (cont'd)